

Shallow Water Dynamics in the Arabian Gulf and Gulf of Oman

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LONG TERM GOALS

The development of a three-dimensional, high resolution nowcast/forecast system for the Arabian Gulf and Gulf of Oman which encompasses scales of 10 km or less when warranted, using the most advanced finite element (FE) coastal hydrodynamic models. The modeled dynamics are to include tidal and wind-driven flow, buoyancy forcing, surface heat flux, river inflow, and turbulent mixing processes.

OBJECTIVE

The primary objective is development of a circulation model for the Arabian Gulf and connecting waters that realistically predicts the complex, 3-D circulation and mixing patterns in the region over seasonal, tidal, sub-tidal, and storm event time scales. Dynamical processes to be considered include the three dominant external forcings in the region, a strong evaporative flux, seasonal wind forcing, and freshwater river discharge. Not only are realistic current fields sought but the hope is to gain understanding of the role each forcing mechanism plays in the strongly thermohaline-driven circulation. A particular emphasis will be placed on the three-dimensional currents and transport of mass, salt and heat through the Strait of Hormuz. Another aim of this study is to demonstrate the utility of the finite element approach using state-of-the-art, physically advanced, 3-D numerical models.

APPROACH

In working toward a nowcast/forecast predictive capability in the Arabian Gulf, two circulation models are employed. The first model, the Dartmouth College QUODDY model, represents the most physically advanced FE model to date. QUODDY is a 3-D, fully nonlinear model that includes tidal, wind-driven, and baroclinic physics, and utilizes advanced turbulence. This model is applied over seasonal and synoptic event time scales in the development of a realistic circulation climatology and in the assessment of individual forcing contributions to the overall circulation. A second model, ADCIRC, is a more probable candidate for real-time predictions and subsequent transition to operations. ADCIRC, now currently only a 3-D nonlinear simulator of tidal and wind-driven physics, is advancing to include a baroclinic component (development by Rick Luetich at UNC). Both finite element models are designed with modular dynamics in which certain mechanisms, such as heat flux, wind forcing, stratification, tides, or river inflow can be independently included or excluded from model equations. This modularity is used to examine the contributions of each component to the overall circulation dynamics.

WORK COMPLETED

The 3-D QUODDY model is applied successfully at the seasonal extremes, January and July, in simulations forced by seasonal hydrography, seasonal winds, and tides. For each month, the initial

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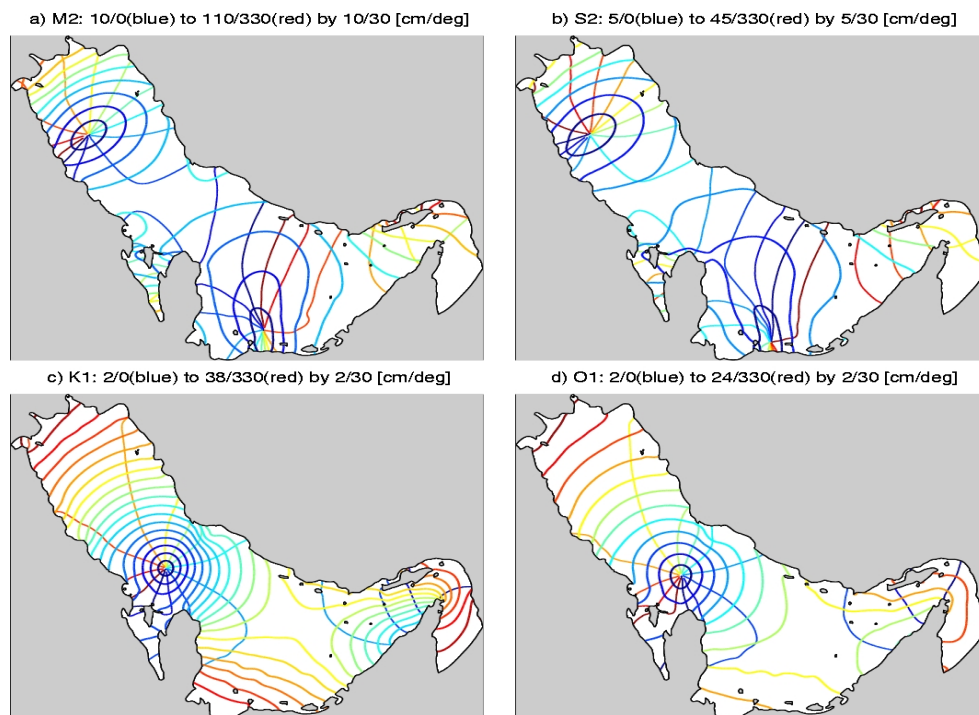
temperature and salinity fields prognostically evolve while subject to tidal rectification and a constant wind stress. A domain selected for the model experiments includes the Arabian Gulf, Strait of Hormuz, and places an open ocean boundary in the Gulf of Oman. Simulations over larger domains reveal numerical instabilities in the vicinity of the steep continental slope in the Gulf of Oman thus restricting computations to the shelf. The finite element mesh itself contains 17440 computational points and has resolution approaching 2 km nearshore. Bathymetry in the Arabian Gulf is taken from the DBDB2 2 minute data base (Naval Oceanographic Office, 1996); an average basin depth is approximately 50 m. Tidal forcing applied at the open is obtained from results of the Grenoble global tide model (LeProvost et al., 1994). Initial hydrography is derived from the MODAS data set (Harding et al., 1998) developed at NRL and constant values for the seasonal mean wind stress are specified from Hellerman and Rosenstein (1983). A series of barotropic, diagnostic, and prognostic solutions are used to identify contributions to the overall circulation from forcing mechanisms associated with density stratification, tides and wind.

Validation is complete for tidal elevations simulated by the 2-D, barotropic ADCIRC model, running operationally at NAVOCEANO. Computed cotidal charts for the Arabian Gulf are shown in Fig. 1. RMS errors using 94 International Hydrographic Office stations range from less than 9 cm in sea surface height to less than 18 degrees in phase. Comparisons between 2-D and 3-D, barotropic velocity fields computed by the ADCIRC model are ongoing to determine if there is an operational advantage to 3-D barotropic current computations.

Several efforts within the Arabian Gulf are just beginning. The first is a data assimilation effort in which each of three linear adjoint models are considered: 1) OTIS, Oregon State University, representer approach; 2) TRUXTON, Dartmouth College, least squares minimization; and 3) a similar model by Thompson, Dalhousie University. The second is an investigation into the sensitivity of Gulf circulation to the source of wind forcing. Wind products currently available are the NSCAT observational winds and the COAMPS model product produced by FNMOC. Other notable advances are: 1) delivery of the first diagnostic, baroclinic ADCIRC model for testing; 2) ongoing collaborations with PET to port the QUODDY model to multiple HPC platforms; and 3) development by Chris Naimie (Dartmouth College) of a set of Matlab and FORTRAN codes that are bundled to create a semi-automated mesh generation software. This software has already been used to create new FE meshes using raw coastline and bathymetry data in three regions worldwide in addition to the Arabian Gulf.

RESULTS

Computed temperature, salinity and density are strongly stratified in summer (Fig. 2). Vertical mixing within the model appears to be overly energetic, e.g. salinity, particularly during winter when waters are less stratified (not shown). Some adjustment in the vertical mixing will be required for future simulations. Partitioning of Gulf circulation in summer with respect to the three forcing mechanisms: tides, baroclinic pressure gradient, and winds, (Fig 3) is presented with respect to the depth-averaged currents. The largest contribution to circulation is the thermo-haline component. As expected flow enters through the Strait and moves up the Iranian coast. A return flow exits the Gulf along the deep channel in the central Gulf. Westerly wind forcing in summer steers currents most dramatically on the shallow Arabian shelf, pushing water out of the Gulf along the southern coast.



1. Cotidal charts for the four primary semi-diurnal and diurnal tidal constituents, M2, S2, K1, O1, in the Arabian Gulf. The model applied is ADCIRC, a 2-D, barotropic simulator that is currently operational at NAVOCEANO.

IMPACT/APPLICATION

Detailed knowledge and understanding of processes governing shallow water dynamics in the Arabian Gulf, Strait of Hormuz, and the Gulf of Oman address Naval needs for anticipating variability in nearshore circulation and water properties over space and time scales relevant to mine-countermeasure, amphibious, or special operations in this priority area. High horizontal resolution currents assist in the planning of instrumentation and tactics associated with amphibious operations as well as search and rescue efforts.

Advantages of an unstructured grid discretization are evident in the placement of open ocean boundaries, localized resolution refinement, and representation of bathymetric and shoreline complexities. A study of this scope, encompassing the Arabian Gulf, Strait of Hormuz, and Gulf of Oman containing localized mesh refinements of less than 5 km, is unprecedented.

TRANSITIONS

Finite element meshes and ADCIRC-2DDI model simulations in the Arabian Gulf were transitioned to A. Baptista at Oregon Graduate Institute, as a test bed for a new FE mesh generator, September, 1999.

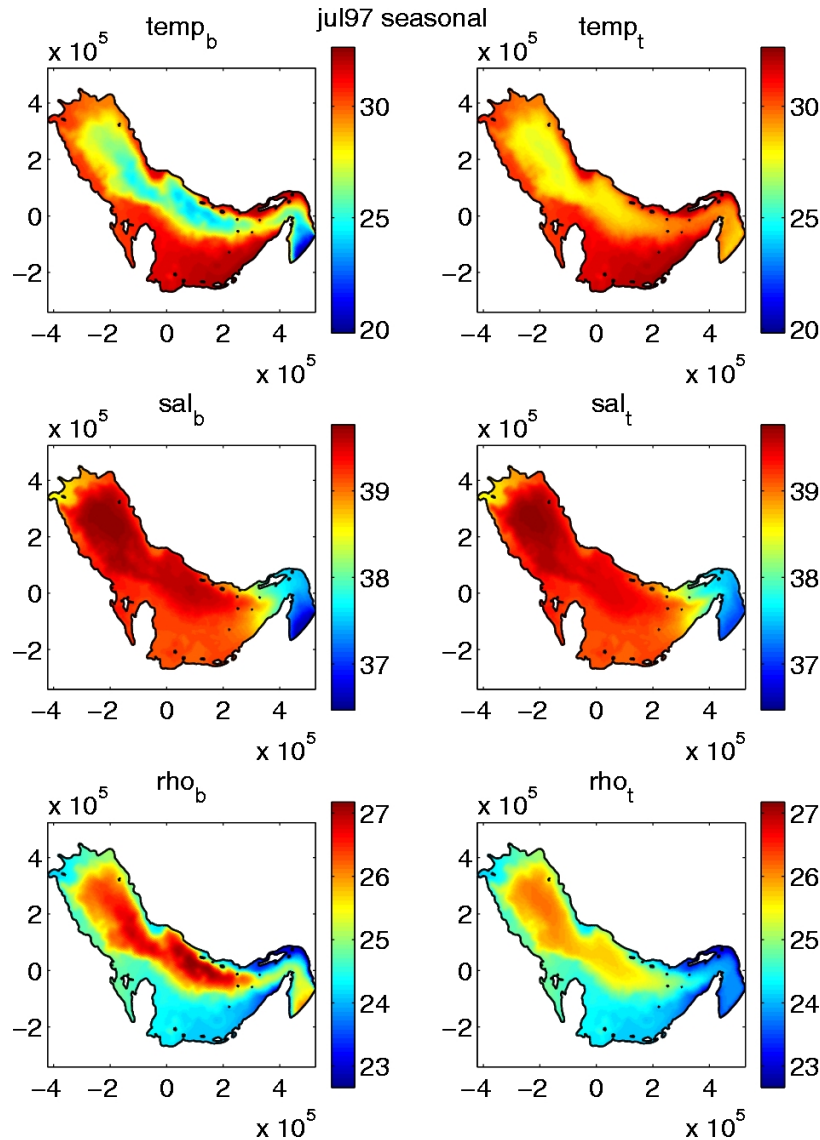
RELATED PROJECTS

Strong interactions exist with C. E. Naimie and D. R. Lynch (Dartmouth College) through the ONR 6.2 "Finite Element Modeling of Coastal Circulation" which is developing a comparable modeling and data assimilation capability in the Yellow Sea. ADCP and CTD observations in the St. of Hormuz are obtained from ONR funded W. B. Johns, (U. Miami). M. Reynolds (Brookhaven National Laboratory)

made available observation taken from the Mt. Mitchell experiment in. Collaborations with R. A. Luetlich (U. North Carolina) are leading to advancement of the ADCIRC model to include baroclinic physics.

PUBLICATIONS

Blain, C. A., “Modeled Three-Dimensional Circulation in a Thermohaline-Driven Marginal Sea”, in Estuarine and Coastal Modeling, Proceedings of the 6th International Conference, M. L. Spaulding and A. F. Blumberg, eds., American Society of Civil Engineers, 1999, *submitted*.



2. Summer Hydrography: Bottom (left) and surface (right) temperature (top), salinity (middle), and density (bottom) computed by prognostic computations with wind forcing.

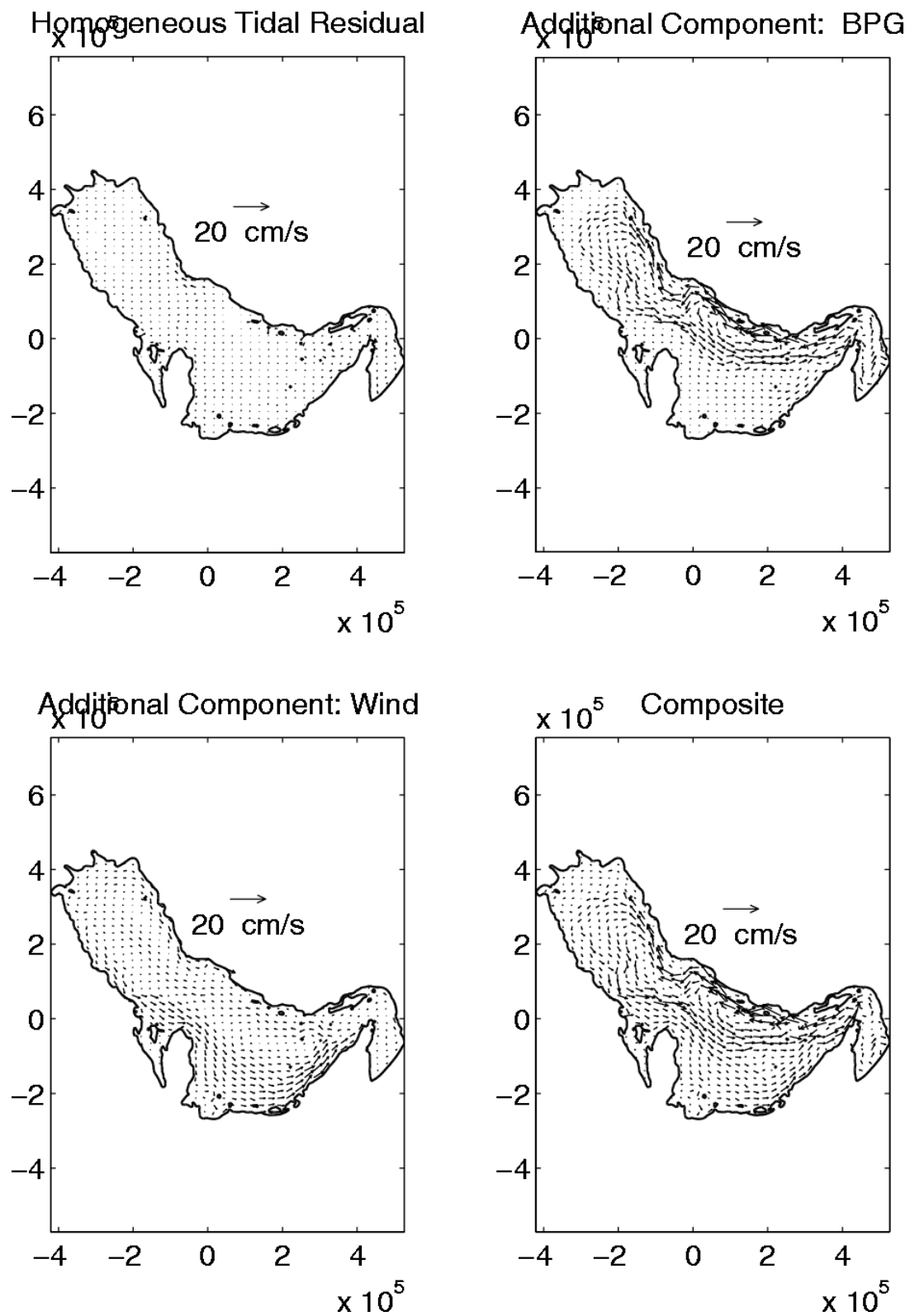


Figure 3. Summer Residual Circulation: Approximate partitioning of the seasonal circulation (bot. right) due to barotropic tidal rectification (top left), baroclinic processes (top right), and wind (bot. left).